
Raytheon

**Air Traffic Management System
Development and Integration
(ATMSDI)**

**CTOD-2.3-2
Draft Guidelines
Subtasks 1-6 for Human Factors Support
for DAG-TM**

December 2001

Contract No.: NAS2-00015

Prepared for

**NASA Ames Research Center
Richard Mogford, Ph.D.**

Prepared by

Raytheon ATMSDI Team

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**Subtask 3 – Human Factors Evaluations of
NASA DAG-TM Concept Elements and
Decision Support Tools**

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EXECUTIVE SUMMARY

Human factors evaluations (HFE) are a critical component of each design phase of any system involving human operators. This guidelines document provides a process for human factors evaluations related to Distributed Air-Ground Traffic Management (DAG-TM) concept elements (CEs) 5 and 11 that relate to *En Route Free Maneuvering* and *Self-Spacing for Merging and In-Trail operations*. Particularly, the guidelines address the activities to examine the feasibility and benefits of CEs 5 and 11. Because DAG-TM concepts shift the roles and responsibilities among decision support tools and the key parties involved in air traffic management activities, the role of human factors evaluations is critical. HFEs will provide important information related to system design that is comprised of people, decision support tools, and operational procedures. The human factors evaluations will also address the benefits of DAG-TM CEs in terms of safety, efficiency, and flexibility of air traffic management. This initial guidelines document will identify a process to conduct HFEs related to CE 5 and CE 11.

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1. BACKGROUND

NASA's Distributed Air-Ground Traffic Management (DAG-TM) represents a paradigm shift where the roles and responsibilities of air traffic service providers (ATSPs), flight crew (FC), and airline operations center (AOC) specialists will change. These changes may alter the distribution of tasks and functions among the key parties and machines, creating new roles for each individual involved in the concept and requiring innovative decision support tools (DSTs) and procedures. Therefore, the benefits and feasibility of DAG-TM concepts need to be investigated before mature concepts, procedures, and DSTs are implemented. As these concepts (or procedures and DSTs) mature through the Technology Readiness Levels (TRLs), they must be continually assessed and evaluated to ensure that these concepts are indeed feasible and beneficial to the NAS. The feasibility assessments include examinations that ensure that the concepts are complete and necessary (FAA, 1999).

This document presents initial guidelines pertaining to Human Factors Evaluations (HFEs) of tasks and environments similar to those expected in the DAG-TM. In general, HFEs in this document refer to paper studies, surveys, fast-time simulations, part-task and full-mission real-time human-in-the-loop (HITL) simulation studies.

2. SCOPE

These initial guidelines were developed based on a literature review, discussions with subject matter experts, author experience, and opinions. These initial guidelines will be updated at the end of FY02 and FY03.

3. OBJECTIVE

This initial guidelines document recommends a process for conducting HFEs to examine the feasibility and benefits of DAG-TM Concept Element (CE) 5 and 11 operations. The guidelines were developed based on the literature review of the best practices or currently established practices of the HFEs, a review of concept elements, discussions with subject matter experts (SMEs), and author experience. These guidelines provide a structure for developing a human factors assessment plan for each CE under consideration.

These initial guidelines will be updated next fiscal year based on additional available information related to DAG-TM validation studies.

Sections 4 and 5 describe DAG-TM CE 5 (En Route Free Maneuvering) and CE 11 (Terminal Self-Spacing). These descriptions are taken from the DAG-TM concept definition documents developed by NASA Ames Research Center (NASA AATT, 1999).

4. DESCRIPTION OF CE 5: EN ROUTE: FREE MANEUVERING FOR USER-PREFERRED SEPARATION ASSURANCE AND LOCAL TFM CONFORMANCE

It is noted that this concept element applies to all flight phases (Departure, Cruise and Arrival) in the operational domain of en route airspace.

4.1 CURRENT PROBLEM

(a) ATSP often responds to potential traffic separation conflicts by issuing trajectory deviations that are excessive or not preferred by users.

In the current air traffic control (ATC) system, trajectory prediction uncertainty leads to excessive ATC deviations for separation assurance. Due to workload limitations, controllers often compensate for this uncertainty (which may be equivalent to or greater than the minimum separation standard) by adding large separation buffers for conflict detection and resolution (CD&R). Although these buffers reduce the rate of missed alerts, some aircraft experience unnecessary deviations from their preferred trajectories due to the unnecessary “resolution” of false alarms (i.e., predicted “conflicts” that would not have materialized had the aircraft continued along their original trajectories). In those cases where a potential conflict really does exist, the buffers lead to conservative resolution maneuvers that result in excessive deviations from the original trajectory. Moreover, the nature of the resolution (change in route, altitude or speed) may not be user-preferred. Due to a lack of adequate traffic, weather, and airspace restriction information (and the means to present such information), and also a lack of conflict resolution tools on the flight deck, current procedures generally do not permit the user to effectively influence controller decisions on conflict resolution.

(b) ATSP often cannot accommodate the user’s trajectory preferences for conformance with local traffic flow management (TFM) constraints.

The dynamic nature of both aircraft operations and NAS operational constraints often result in a need to change a 4-D trajectory plan while the aircraft is en route. Currently, the user (FC or AOC) is required to submit a request for a trajectory change to the ATSP for approval. During flow-rate constrained operations, the ATSP is rarely able to consider user preferences for conformance. Additionally, a lack of accurate information on local traffic and/or active local TFM constraints (bad weather, special use airspace (SUA), airspace congestion, arrival metering/spacing) can result in the FC or AOC requesting an unacceptable trajectory. The ATSP is forced to plan and implement clearances that meet separation and local TFM constraints, but may not meet user preferences. Further negotiation between the ATSP and FC can adversely impact voice-communication channels and increase ATSP and FC workload.

4.2 SOLUTION (FLIGHT DECK FOCUS)

(a, b) Appropriately equipped aircraft accept the responsibility to maintain separation from other aircraft, while exercising the authority to freely

maneuver in en route airspace in order to establish a new user-preferred trajectory that conforms to any active local TFM constraints.

While in the en route operational domain, appropriately equipped aircraft are given the authority, capability and procedures needed to execute user-preferred trajectory changes without requesting ATSP clearance to do so. Along with this authority, the flight crew takes on the responsibility to ensure that the trajectory change does not generate near-term conflicts with other aircraft in the vicinity. The trajectory change should also conform to any active local TFM constraints (bad weather, SUA, airspace congestion, arrival metering/spacing). User-preferred trajectory modification may be generated by the FC with AOC input if appropriate, or generated entirely by the AOC and transmitted to the FC via datalink. The FC broadcasts its modified flight plan via datalink (includes notification of ATSP) immediately after initiation of trajectory modification; in most situations, this task is handled by on-board automation.

The ATSP monitors separation conformance for free maneuvering aircraft, and provides separation assurance for lesser-equipped aircraft using CD&R DSTs. The ATSP may act on behalf of lesser-equipped aircraft when they are in potential conflict with free maneuvering aircraft. For cases where the flight crew attempts, and fails, to resolve a conflict, automated systems or the ATSP will provide a required resolution. Procedures and flight rules are established that provide incentive for aircraft to equip for self-separation, such as, perhaps, priority status in conflicts with lesser-equipped aircraft.

4.3 POTENTIAL BENEFITS OF CE 5 OPERATIONS

The potential benefits of CE 5 operations are:

- Reduction in excessive and non-preferred deviations for separation assurance and local TFM conformance, due to the ability of the flight crew (for equipped aircraft) to self-separate and maintain local TFM conformance according to their preferences.
- Increased safety in separation assurance for all aircraft, due to communications, navigation, and surveillance redundancy (FC as primary and ATC as backup) and increased situational awareness on the FC of appropriately equipped aircraft.
- Reduced ATSP workload for separation assurance and local TFM conformance plus reduced FC workload for communications, due to the distribution of responsibility for separation assurance and local TFM conformance between the ATSP and appropriately equipped FCs.

Detailed description of CE 5 can be found in Philips (2000).

5. DESCRIPTION OF CE 11: TERMINAL ARRIVAL: SELF-SPACING FOR MERGING AND IN-TRAIL SEPARATION

5.1 CURRENT PROBLEM

Excessive in-trail spacing buffers in arrival streams reduce runway throughput and airport capacity, especially in conditions of poor visibility and /or low ceilings.

In terminal area environments for which arrival demand approaches or exceeds capacity, aircraft landing rates are significantly lower under instrument meteorological conditions (IMC) than under visual meteorological conditions (VMC). In order to compensate for uncertainties in aircraft performance and position, the ATSP applies in-trail spacing buffers to arrival streams under IMC in order to ensure that minimum separation requirements between successive aircraft are met. The resulting generous arrival spacing reduces runway throughput below its capacity to accept aircraft.

5.2 SOLUTION (FLIGHT DECK FOCUS)

Appropriately equipped aircraft are given clearance to merge with another arrival stream, and/or maintain in-trail separation relative to a leading aircraft.

In VMC, aircraft are often able to maintain closer spacing during the approach, thereby increasing the capacity of the terminal area and the runway acceptance rate. In the current system, the FC is often requested to accept responsibility for visual self-separation once they acknowledge they can see the leading aircraft. In this situation, the FC is responsible for determining and then maintaining a safe separation from other aircraft, and is therefore not subject to the ATSP minimum separation requirements.

Self-spacing operations will enable the FC to autonomously merge with another arrival stream and/or maintain in-trail separation with another aircraft under IMC as they would under VMC, thus significantly increasing arrival throughput. Self-spacing applies to aircraft that are subject to spacing requirements during arrival from the feeder fix to the final approach fix.

Anticipated procedures for self-spacing involve the ATSP transferring responsibility for in-trail separation to properly equipped aircraft, while retaining responsibility for separating these aircraft from crossing traffic. Once the FC receives clearance to maintain spacing relative to a designated leading aircraft, the FC establishes and maintains a relative position with monitoring and speed/course adjustments. Under some conditions, information such as required time of arrival at the final approach fix may be provided by an appropriate ATSP-based DST, thereby enabling accurate inter-arrival spacing that accounts for differing final approach speeds or wake vortex avoidance. ATSP monitors all aircraft to ensure adequate separation. For cases where the flight crew fails to maintain adequate spacing, automated systems or the ATSP will provide a required correction.

The self-spacing concept is expected to make use of datalink capabilities to provide position information and a cockpit display of traffic information (CDTI) and/or advanced flight director/head-up guidance technology to provide spatial and temporal situation awareness to the flight crew. FC-based DSTs will provide information to enable station-keeping and/or monitoring of automatic 4D trajectory management.

Detailed description of CE 11 can be found in Sorensen (2000).

5.3 POTENTIAL BENEFITS OF CE 11 OPERATIONS

The potential benefits of CE 11 operations are:

- Increased arrival capacity/throughput in IMC, due to a reduction in excessive spacing buffers resulting from the ability of appropriately equipped aircraft to operate as if they were in VMC.

- Reduced ATSP workload, due to transfer of separation responsibility to the flight crew of appropriately equipped aircraft.

6. GUIDELINES FOR DEVELOPING INITIAL HUMAN FACTORS ASSESSMENT AND RESEARCH PLANS

The following guidelines section describes an outline of the human factors evaluation plans that will be developed for CE 5 and CE 11. These guidelines are primarily meant for the DAG-TM researchers but would be useful for system designers, SME opinions, sponsors, academic researchers, and managers.

6.1 OVERALL INITIAL GUIDELINES

The human factors evaluation plan should address the following:

- Review of CE 5: Free Maneuvering and CE 11: Self Spacing for Merging and In-Trail Separations operational concepts,
- Existing or proposed computer-human interface design considerations,
- Controller and pilot procedures,
- Integration of CE operations with the current National Airspace System,
- Human factors issues and research questions that should be addressed during CE validation process,
- Different HFEs that must be conducted at each TRL,
- Human factors involvement in the research and development of DAG-TM CEs, and
- Users involvement in the CE development.

6.2 INITIAL GUIDELINES

The following sections provide details related to the above guidelines.

6.2.1 Review of CE 5 and CE 11 Operational Concepts

It is recognized that the HFEs for validating CE 5 and CE 11 are unique. Therefore, CE 5 and CE 11 description must be carefully examined. In addition, the transition between CE 5 and CE 11 should be considered. Although this fiscal year (FY01) priorities only included CE 5 and CE 11 activities, the next fiscal year will cover CE 5, CE 6 (En Route Trajectory Negotiation), CE 7 (En Route Collaboration for TFM Constraints) and CE 11 operations. Philips (2000) provides a detailed description of CE 5 and Sorensen (2000) provides a detailed description of CE 11.

6.2.2 Existing and Proposed Computer-Human Interface Considerations

The CDTI interface design guidelines were recently developed. It is expected that the guidelines development activity will be continued for next two years. The CDTI guidelines provide recommendations for the information and presentation needs for CE 5 and 11.

In addition, the air traffic control DSTs that will support CE 5 and CE 11 operations from ATSP need to be carefully examined. Particularly, the ATSP display already has a number of menus, input-output devices, and display characteristics. The new DSTs must be compatible with the current interfaces. Therefore, careful consideration must be provided to the following:

- Input format of information,
- Output format of information,
- Interaction method,
- Communication methods,
- Use of color,
- Font size and type, and
- Adaptability of display characteristics to individual needs.

It is recognized that optimal displays and interaction methods would help provide optimal human performance. However, it must be recognized that development of optimal displays and interaction methods at this stage is too premature since the concept elements themselves are evolving. As a result, the information needs themselves would change. Therefore, it may be better to finalize the interaction considerations at the later TRL stages.

6.2.3 Controller and Pilot Procedures

Currently, pilots do not do self-separation or free maneuvering (except operating under visual flight rule conditions). However, CE 5: Free Maneuvering shifts the separation responsibility from the ATSP to the FC. With such a shift in responsibilities, the following needs to be investigated:

- Role of ATSP and FC under nominal CE 5 and CE 11,
- Procedure for cancellation of CE 5 or CE 11 operation and shifting responsibility to ground,
- Procedure for resuming the CE 5 and CE 11 operation,
- Legal responsibility of loss of separation under CE 5 and CE 11,
- Accommodation of non-equipped aircraft,
- Transition procedure between CE 5 and CE 11, and
- Phraseology to support CE 5 and CE 11 operations as well as their cancellation and resumption.

In order to investigate procedural needs the following scenarios must be considered:

- Routine nominal scenario with moderate to low traffic,
- Routine nominal scenario heavy traffic,
- Nominal scenario with different weather situations (winds, severe weather, low visibility, etc.), and

- Off-nominal scenario with deviations, emergencies, loss of communications, and equipment failures.

6.2.4 Integration of CE Operations with the Current National Airspace System

It is recognized that new DSTs and concepts must be gradually implemented in NAS. Such incremental implementation will reduce the risk of drastic change in equipment and procedures. However, a thorough investigation of new DSTs (together with existing equipment) must be conducted to examine the following:

- Changes in ATSP and FC tasks,
- Changes in performance as a result of new tasks, and
- Changes in information needs.

In order to examine the feasibility and benefits of CE 5 and CE 11, the researcher should adopt “*build-a-little, demonstrate-a-little, and experiment-a-little*” philosophy to ensure that the enhancements in concepts and technology are incremental. Such an incremental approach modifies a few variables at one time ensuring that the benefits are traced to each modification. Additionally, an incremental approach is easier for user acceptance and offers flexibility for modifications at any stage.

If there are additional information needs (beyond currently available information), then these must be carefully supported by DSTs that will be integrated with existing systems.

6.2.5 Human Factors Issues and Research Questions that Should be Addressed During CE Validation Process

Since both CE 5 and CE 11 change the roles and responsibilities of human parties involved in the air traffic management (ATM), we must ensure that such changes do not adversely affect the human performance (and ideally should enhance human and therefore system performance). The following human performance issues need to be addressed.

- Impact of changes on ATSP, FC, and AOC workload (redistribution of workload),
- Impact of changes on ATSP, FC, and AOC situation awareness (redistribution of situation awareness),
- Impact on FC and ATSP heads down time as a result of new DSTs,
- Impact of CEs on error potential, and
- Impact of CE procedures and DSTs on CE procedures and accuracy.

In addition to identifying the above impacts, the following issues must be examined.

- The look ahead time and frequency of aircraft intent information from FC to ATSP,
- The look ahead time and frequency of aircraft intent information from one aircraft to other aircraft,
- The need to know the party that is in charge of the separation,

- Harmonization of different conflict detection options (e.g., regarding air and ground side conflict alerts-- should they have the same look ahead time and probe frequency for conflict alerts?),
- Harmonization of conflict resolution options (e.g., should flight deck tools suggest conflict resolution options based on what is best for their own aircraft, if so, how will such suggestions be perceived by the ground side? Likewise, should groundside tools suggest conflict resolution options based on what is best for the airspace under control? Will there be any mismatch of expectations and goals (e.g., fuel savings, airspace efficiency) between the ATSP and FC?
- What type of training must be provided to the ATSP, FC, and AOCs to implement CE 5 and CE 11 concepts?
- What are the benefits of CE 5 and CE 11 to the ATSP, FC, and AOCs?
- Particularly in CE 11, when does spacing become separation critical and who decides when an action must be taken to avoid potential loss of separation?
- Identify different human factors evaluations that must be conducted at each TRL,
- Is it possible for the ATSP to take over a potentially dangerous situation that was not resolved by the FC and vice a versa? Are there any potential vigilance related issues? It must be noted that the ultimate test is the ability of the human to take over and swiftly manage ATM situations that are rare (e.g., emergencies, equipment failures, etc.). Therefore, all such situations must be examined to ensure that human operators can recover the situations safely.

6.2.6 Different HFEs that must be Conducted at Each TRL

The researchers will examine subtasks 1, 2, 4, 5, and 6 literature reviews and guidelines and identify human factors evaluations that must be conducted at each TRL.

It is postulated that the human factors evaluations will involve paper studies (e.g., task analysis, cognitive walkthroughs), part-task simulation studies, and full mission simulations involving one or all elements of the DAG-TM triad.

A number of feasibility studies and concept exploration studies can be planned that will specifically address CE 5, CE 6, CE 7, and CE 11 concept elements. These studies should focus on the overall concept, supporting decision support tools, and procedures. The objective of the studies is to examine the benefits and feasibility of these concepts. It is recognized that the fidelity of studies will increase as the concepts mature through different stages of TRL. Refer to Subtask 5 Guidelines Simulation Requirements (Kopardekar, Sacco, & Carmen, 2001) for information regarding the necessary fidelity of simulations conducted at each TRL.

During the course of the DAG-TM evaluations, a number of HFEs will be implemented. For each study, at each phase of development, the appropriate evaluation method and measurement techniques must be considered. Individualized techniques must be developed for each study.

6.2.7 Human Factors Involvement in the Research and Development of DAG-TM CEs

The human factors involvement must be addressed in the early stages of concept or tool development. Typically, it is believed that the sooner the human factors considerations are

addressed, the better the end product would be. By considering human factors aspects early stages of design ensures that the system will use human capabilities and will not negatively impact human performance.

6.2.8 Users Involvement in the CE Development

The early human factors involvement typically calls for an early user input. However, it must be noted that user opinions and desires must be carefully separated from user needs. The test of such differences is whether any enhancements suggested by users provide any system or human benefit. Obviously, cost-benefit assessments must be done to weigh tradeoffs among multiple alternatives.

Regarding CEs 5, 6, and 7, en route controller, flight crew, and dispatcher involvement is crucial. Regarding CE 11, terminal controller, flight crew, and dispatcher involvement is crucial. The transition issues between terminal and en route must be carefully considered particularly for procedural implications. User involvement will identify the procedural implications and information needs to perform these operations. Such activities may also provide insight to the researchers where they may meet resistance in trying to get the concept of operations accepted in the field. It is recommended that focus group activities need to be conducted for each party. Additionally, a combined focus group activity needs to be conducted periodically to review the collective development of procedures, information needs, and decision support tool requirements. For conducting such focus groups, a concept demonstration or storyboarding type activity is beneficial. Such activity also demonstrates the use of the current decision support tools designed for the concept and allows for testing the information display requirements. User involvement would help identify information needs, initial procedures, phraseology needs, display characteristics, decision support tool needs, and other considerations.

To address the above considerations, the following types of activities will be conducted:

- Subject matter expert focus groups,
- Cognitive walkthroughs,
- Concept and technology demonstrations,
- Fast-time simulations,
- Prototyping, and
- Real-time HITL simulations.

In the next year's revision, the guidelines will address the status of CEs with respect to TRLs and the type of activities that will need to be accomplished to move to the next TRL.

In summary, the guidelines described above would be beneficial in developing initial human factors evaluation plan for DAG-TM CE 5 and CE 11. These guidelines will be updated in FY02 and FY03.

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ACRONYM LIST

AATT	Advanced Air Transportation Technologies
AOC	Airline Operations Center
ATC	Air Traffic Control
ATM	Air Traffic Management
ATSP	Air Traffic Service Provider
CDTI	Cockpit Display of Traffic Information with Alert Logic
CD & R	Conflict Detection and Resolution
CE	Concept Elements
DAG-TM	Distributed Air-Ground Traffic Management
DST	Decision Support Tool
FAA	Federal Aviation Administration
FC	Flight Crew
HFE	Human Factors Evaluation
IMC	Instrument Meteorological Conditions
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
SME	Subject Matter Expert
SUA	Special Use Airspace
TFM	Traffic Flow Management
TRL	Technology Readiness Level
VMC	Visual Meteorological Conditions

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